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• ISSN 2721 - 0871 (online)
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INTERNATIONAL JOURNAL OF ENVIRONMENTAL, SUSTAINABILITY AND SOCIAL SCIENCE
Indexed By :

UNVEILING THE GREEN IMPACT: EXPLORING THE NEXUS BETWEEN TRADE OPENNESS AND ENVIRONMENTAL QUALITY IN SOUTH AFRICA

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Volume: 4
Number: 5
Page: 1302 - 1320

Article History:
Received: 2023-08-03
Revised: 2023-08-29
Accepted: 2023-09-15

Abstract:
In light of the escalating concerns about environmental sustainability and the profound impact of international trade on environmental outcomes, the study's focal point was to empirically investigate the relationship between trade openness and environmental quality in South Africa from 1994 to 2018. In order to achieve the goal, the research utilized the Autoregressive Distributed Lag (ARDL) Bounds method and Granger causality test for analyzing data. The ARDL Bounds approach was chosen for its ability to examine both short-run and long-run relationships, while the Granger causality test provided insights into the direction of causality between the variables. This combination of robust econometric techniques enhances the reliability and depth of the study's findings, leading to a more comprehensive understanding of the complex relationship between trade openness and environmental quality in the country. The analysis results revealed a significant and positive relationship between trade openness and carbon emissions in the short and long run. The Granger causality test also indicated a unidirectional causality from trade openness to environmental quality. These implications are paramount for the South African government's policy formulation. In order to tackle the environmental issues that come with open trade, the government must put in place trade agreements that will enhance its ability to address these concerns efficiently. One crucial step is reducing trade barriers on environmental goods, facilitating increased access to green technologies at lower costs. Moreover, the government should prioritize enacting and enforcing strict environmental laws to avoid the "pollution haven hypothesis," which often affects low-income countries.

Keywords: Trade Openness, Carbon Emissions, Granger Causality Test, Autoregressive Distributed Lag Bounds (ARDL), South Africa.

Cite this as: DINGISWAY, U., SIBANDA, K., DUBIHLELA, D. (2023). "Unveiling the Green Impact: Exploring the Nexus between Trade Openness and Environmental Quality in South Africa." International Journal of Environmental, Sustainability, and Social Science, 4 (5), 1302 – 1320.

INTRODUCTION

The increasing concerns about environmental sustainability and the prominent role of international trade in shaping environmental outcomes have raised pivotal questions about the relationship between trade openness and environmental quality (Udeagha & Ngepah, 2022). South Africa faces unique challenges in balancing economic growth with environmental conservation as a resource-rich and trade-dependent nation. While several studies (Van Tran, 2020; Iorember et al., 2021; Udeagha & Ngepah, 2022) have explored this nexus in various contexts, a significant gap remains in understanding the specific dynamics within South Africa. This research aims to contribute to the existing literature by empirically examining the relationship between trade openness and environmental quality in South Africa. By shedding light on this intricate connection,

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the study seeks to provide valuable insights for policymakers, businesses, and environmental advocates to formulate sustainable and environmentally responsible trade policies.

South Africa's transition to a liberalized and trade-oriented economy in the post-apartheid era has been accompanied by heightened awareness of environmental issues (Iorember et al., 2021). The tension between economic development and environmental conservation has prompted numerous debates on the potential impacts of trade openness on environmental quality (Shahbaz et al., 2017). Scholars have put forth divergent arguments regarding the nature of this relationship, with some positing that increased trade can lead to environmental degradation, while others argue that trade openness can stimulate the adoption of cleaner technologies and environmental regulations (Chen & Huang, 2019; Frankel & Rose, 2005). The situation in South Africa is further complicated by the country's rich endowment of natural resources, including minerals and agricultural products, which play a crucial role in international trade (World Bank, 2020). As such, the need to understand the implications of trade openness on the environment becomes particularly pressing for South Africa. However, previous research on this topic has been limited, and few studies have delved into the specific dynamics within the country (Udeagha & Ngepah, 2022).

South Africa is a significant contributor to global CO_2 emissions, accounting for 1.09 percent of all emissions in the world in 2020 (World Bank, 2021). On a global scale, the country ranks 14th for its annual carbon dioxide emissions. The burning of coal, a significant contributor to carbon dioxide emissions, is the most evident cause of this (Udeagha & Ngepah, 2022). At the end of 2020, South Africa had amassed 35,053 Million Short of Tons (MMst) of proved coal reserves, placing it eighth globally and accounting for roughly 3.68 percent of the world's total coal reserves of 1,139,471 MMst (Udeagha & Ngepah, 2022).

In the last few decades, environmental protection has risen to prominence on the international agenda, reflecting broad worries about environmental degradation (Gill et al., 2018). Since the 1970s, when groups like North American Free Trade Agreement (NAFTA) and the World Trade Organisation (WTO) worked to increase trade openness, there has been discussion about the relationship between the environment and international trade (Le et al., 2016; Ibrahim & Ajide, 2022; Khan et al.,2022).

The environmental effects of trade became an increasingly pressing concern in trade policy (Le et al., 2016; Iorember et al.,2021). Environmental economists have linked the globalization of trade to the depletion of natural resources and the release of more carbon dioxide (CO_2), which adversely affects the environment (Iorember et al., 2021). The literature on the trade-environment nexus is typically split into the optimistic and pessimistic (Van Tran, 2020). The optimistic researchers argue that trade openness has favorable environmental outcomes, Shahbaz et al., (2017), while on the other hand, the pessimistic researchers have found a negative correlation (Le et al., 2016). Globally, the empirical relationship between trade openness and environmental quality has been studied by numerous researchers over the past few decades; nevertheless, the results have been essentially contradictory (Managi et al., 2009; Beladi & Oladi, 2011; Shahbaz et al., 2017; Soylu et al., 2021).

South Africa is witnessing significant growth in trade openness, yet more effort needs to be made to examine the environmental repercussions of trade openness in this country. Previous studies have been conducted primarily on developed nations and China (Khan et al., 2021). This study adopts a robust methodological approach to bridge the existing gap in the literature and provide a more comprehensive understanding of the trade openness-environmental quality relationship in South Africa. The Autoregressive Distributed Lag (ARDL) Bounds technique examines short-run and long-run relationships between trade openness and environmental quality, considering potential dynamic effects over time (Pesaran et al., 2001). Additionally, incorporating the Granger causality test allows for exploring the direction of causality between these variables

(Pesaran et al., 2001). Therefore, the study aims to furnish empirically grounded insights into the complex interplay between trade openness and environmental quality in South Africa. The findings are anticipated to offer valuable guidance for policymakers and stakeholders in formulating effective and sustainable trade policies that foster economic growth and safeguard and promote environmental conservation.

Review of the literature. This section presents the theoretical background and empirical findings from other studies related to this study. The section first discusses theoretical literature under three channels and the Kuznets curve and then presents the empirical reviews from previous studies.

Theoretical Literature. This section delves into various theoretical approaches to elucidate the relationship between international trade and the environment. Three main channels, namely the scale effect, composition effect, and technique effect, have been identified as mechanisms through which trade can impact the environment (Copeland & Taylor, 2013). The scale effect suggests that trade liberalization and increased economic activity could lead to a larger production scale, potentially exerting additional strain on the environment (Le et al., 2016). The composition effect focuses on shifts in production between countries, where developing nations might concentrate on manufacturing polluting goods due to lax environmental regulations, while developed countries prioritize cleaner production (Le et al., 2016; Copeland & Taylor, 2013). The technique effect evaluates adopting more ecologically sustainable manufacturing practices in response to market and institutional incentives (Vilas-Ghiso & Liverman, 2006).

Additionally, the section introduces two prominent theories concerning environmental quality and trade. The Environmental Kuznets Hypothesis (EKC) posits an inverted U-shaped relationship between per capita pollution and income, suggesting that as income rises, pollution increases until a certain income level, beyond which pollution declines (Le et al., 2016; Managi, 2009). On the other hand, the Pollution Heaven Hypothesis (PHH) proposes that emerging countries with less stringent environmental regulations may become pollution havens and specialize in producing highly polluting goods. At the same time, industrialized nations focus on less polluting products (Gill et al., 2018). However, empirical evidence on both theories remains conflicting and inconclusive, with studies offering varying degrees of support or refutation (Dinda, 2004; Jaffe et al., 1995; Tobey, 1990).

In conclusion, this section provides an overview of the study's theoretical literature, setting the stage for the empirical investigation into the relationship between trade openness and environmental quality in South Africa. By exploring these theoretical frameworks, the study aims to contribute to a deeper understanding of the complex interactions between trade and the environment, offering valuable insights for policy formulation and environmental management.

Empirical Literature. Several studies have examined the relationship between trade openness and environmental quality using various econometric methods. Le et al. (2016) found that as trade liberalization grew, global environmental conditions deteriorated, supporting the notion that more prosperous countries may export pollution to poorer nations. Similarly, Van Tran (2020) explored the environmental effects of trade openness in developing countries and observed a potentially harmful impact on the planet, despite evidence of an environmental Kuznets curve hypothesis. Atsu et al. (2021) and Iorember et al. (2021) utilized the Autoregressive Distributed Lag (ARDL) approach to analyze South Africa's environmental aspects.

Atsu et al. (2021) focused on ICT, energy consumption, and financial development, while Iorember et al. (2021) examined the impact of renewable energy use, human capital, and trade on the ecological footprint. Both studies found that trade openness had a long-term effect on environmental quality, with economic expansion having a short-term impact on ecological

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footprints. The findings of these studies collectively contribute to understanding the complex relationship between trade openness and environmental quality, particularly in South Africa's comparative advantage in pollution-intensive product export and production, which has significant implications for the country's environmental deterioration.

METHODS

Model Specification. This study bases its model on the research by (Iorember et al., 2021), which compared the impacts of liberalization, economic progress, and renewable energy consumption on environmental protection in developing nations. Equation 1 represents the time series model developed (Iorember et al., 2021).

$$EQ\ = f(REC, TOP, GDP)$$

Where $CO2$ is carbon emission, which measures environmental quality**,** TOP is trade openness*;* REC is renewable energy consumption**.**

The functional form above was explained in the equation below.

$$InCO_{2t} = \propto_0 + \propto_1 InREC_t + \propto_2 InTOP_t + \propto_3 InGDP_t + \mu_t$$

$\propto_0$ and μ_t are the constant and white noise stochastic terms, respectively. Environmental quality is a critical variable in obtaining reliable data and examining these broader indicators of environmental quality (Van Tran, 2020). Carbon emissions will be utilized as an environmental quality indicator. The combined import and export ratios to GDP are the most frequent way to measure trade openness. Trade openness is measured by the nominal import/export ratio to GDP (Van Tran, 2020).

Other factors influencing environmental quality are primary energy consumption (PEC), Population growth (PG). Deforestation, a significant source of greenhouse gas emissions, may be exacerbated by a rising population (Shi, 2001). The emergence of global warming issues can be directly attributed to our insatiable appetite for energy.

$$InCO_{2t} = \propto_0 + \propto_1 lnTOP_t + \propto_2 lnPEC_t + \propto_3 lnPG_t + \mu_t$$

In this equation, CO_2 represents environmental quality, TOP represents trade openness, PEC represents primary energy consumption, and PG represents population growth. B_0 is the fixed value, and μ_t is the disturbance term considering exogenous factors affecting the solution. Explanatory variables have coefficients denoted by $\propto_1, \propto_2, \propto_3$.

Data Sources. Data used in this study is from 1994 to 2018 yearly series. Data was sourced from the global economy database. The global economy database was used as it is one of the credible data sources. The period was chosen due to data availability for all variables at the time of the research.

Estimation technique. A unit root test was performed to avoid false results and determine if there is a cointegration relationship in the variables. This study used the Augmented Dickey-Fuller (ADF) and Philips Peron (PP) tests (Brooks, 2002).

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The study employed the ARDL method, which was created by Pesaran et al. (2001) as a cointegration test was used in this study (Iheanacho, 2017). This approach is relatively new and has many advantages over the classical cointegration tests. The model works with limited data because it relies on the lag distribution and considers the dependent variable's historical values (Chen et al., 2007). Coefficient estimates will be biased if lagged values of the dependent variable are included as regressors; hence they have been left out (Mukhtarov et al., 2020). This study's data properties make applying the Autoregressive Distributed Lag (ARDL) approach particularly suitable. The ARDL model is well-suited for datasets that exhibit non-stationary properties and includes an I(0), I(1), or a mix of I(0) and I(1) variables. This characteristic is crucial for investigating the long-run relationships between trade openness and environmental quality, as economic and environmental variables have different integration orders. The ARDL technique allows for estimating cointegrating relationships among these variables, offering a robust framework to analyze their long-term associations (Pesaran et al., 2001). Additionally, the ARDL approach accommodates small sample sizes, making it advantageous for studies with limited observations, as it can still yield reliable and meaningful results (Mukhtarov et al., 2020).

A causality relationship within the series was detected through the Granger procedure, and cointegration results suggest that causality may run in one direction (Toloui, 2018). In this study, Mukhtarov et al. (2020) explored Granger block causality between energy consumption and its determinants to ascertain the direction of influence among the variables.

Diagnostic and stability tests were conducted to ensure the model does not suffer from autoregressive conditional heteroscedasticity. The diagnostic tests aim to determine how reliable the ARDL method is (Iheanacho, 2017). Thus, diagnostic tests were used in the research to check serial correlation, heteroscedasticity, and normality. The stability test is a regression error test, and the null hypothesis states that there is no misspecification, and the alternative hypothesis is that there is misspecification (Gujarati, 2022). Cumulative sum of recursive residuals (CUSUM) test and Cusum of squares (CUSUMQ) test are performed in this study to ascertain the stability of parameters in the long run in the ARDL model.

RESULT AND DISCUSSION

This section presents the results of descriptive statistics to help identify the qualities of the data. Table 1 below displays the findings of the descriptive statistics.

Table 1: Descriptive Statistics

	CO2PC	TO	PEC	PG
Mean	7.453600	50.44600	1314.088	1.507200
Median	7.630000	50.41000	1360.819	1.460000
Maximum	8.570000	65.97000	1479.388	2.320000
Minimum	6.210000	37.11000	1068.537	1.220000
Std. Dev.	0.722316	7.109446	137.8397	0.276232
Skewness	-0.456081	0.027652	-0.319537	1.495019
Kurtosis	1.882233	2.354309	1.509527	4.851404
Jarque-Bera	2.168170	0.437474	2.739507	12.88336
Probability	0.338211	0.803533	0.254170	0.001594

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Sum	186.3400	1261.150	32852.20	37.68000
Sum Sq. Dev.	12.52178	1213.061	455994.7	1.831304
Observations	25	25	25	25

Source: Authors' drawing. Results obtained from Eviews 10

The data showed that the average amount of carbon emissions was 7.453600, and the standard deviation was 0.722316. A negative skewness of 0.456081 and an asymmetric tail with a greater tendency toward negative values indicate a high distribution, as shown by the kurtosis value of 1.882233. With a mean of 50.44600, a standard deviation of 7.109446, and a kurtosis of 2.354309, trade openness exhibited a relatively strong distribution with heavier tails. An asymmetric tail favoring larger positive values is indicated by the skewness of 0.027652, which is positive. The primary energy consumption statistic was positively skewed (negative skewness = 0.319537) with a mean of 1314.088, a high standard deviation of 137.83f97, and a kurtosis of 1.509527. There was a mean population increase of 1.507200 and a standard deviation of 0.276232. High dispersion was indicated by the Kurtosis value of 4.851404. A skewness of 1.495019 is positive, indicating that the tail of the distribution is more heavily weighted toward positive values.

The statistics in Table 1 show, in brief, that none of the variables were abnormal and that there was a low probability that they would have a Jarque-Bera distribution, proving that the variables were normally distributed.

Formal Unit Root. The unit root tests run to determine the optimal order of integration for the ARDL modeling approach are described in this section (Mukhtarov et al.,2020). Multiple unit root tests are utilized to ensure the reliability of the results. The levels and first difference between ADF and PP results are presented in Tables 2 and 3.

Tale 2: Augmented Dickey-Fuller test

Variables	Model Specification	t-static	Order of Integration	p-value
LCO2PC	Trend and Intercept	-1.176694	I (0)	0.8927
	Trend and Intercept	-5.255983***	I (1)	0.0017
LTO	Trend and Intercept	-3.027675	I (0)	0.1456
	Trend and Intercept	-5.195777***	I (1)	0.0028
LPEC	Trend and Intercept	-1.777703	I (0)	0.6837
	Trend and Intercept	-4.537362***	I (1)	0.0082
LPG	Trend and Intercept	-3.144875	I (0)	0.1221
	Trend and Intercept	-3.780510***	I (1)	0.0065

Note: *, **, and *** represents 10%, 5%, and 1 % respectively level of significance, respectively. Source: Authors' drawing. Results obtained from Eviews 10

Results from Table 2 show that carbon emission, trade openness, primary energy consumption, and population growth were non-stationary at the level. These variables became

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stationary after being differenced once. Moreover, to confirm stationarity, at a 10% significant level, these four variables had test statistic values that were more than that of a critical value. These results were validated with those from the PP test shown in the table below.

Table 3: Phillips-Perron

Variables	Model Specification	t-static	Order of Integration	p-value
LCO2PC	Trend and Intercept	-1.056425	I (0)	0.9159
	Trend and Intercept	-5.502872***	I (1)	0.0010
LTO	Trend and Intercept	-3.062505	I (0)	0.1372
	Trend and intercept	-8.334687***	I (1)	0.0000
LPEC	Trend and Intercept	-1.671868	I (0)	0.7322
	Trend and Intercept	-6.896212***	I (1)	0.0001
LPG	Trend and Intercept	-2.541175	I (0)	0.3074
	Trend and Intercept	-3.109118**	I (1)	0.0345

Note: *, **, and *** represents 10%, 5%, and 1 % respectively level of significance, respectively. Source: Authors' drawing. Results obtained from EViews 10

Results from Table 3 show that PP confirmed the results from the ADF test: that carbon emission, trade openness, primary energy consumption, and population growth were nonstationary at levels. However, they became stationary after being differenced once. All variables had test statistic values that were more than that of a critical value and significant at 10%. In a nutshell, the results showed that variables are stationary at first difference. These results warrant using the ARDL model since it is compatible with I (0), I (1), or a combination of the two.

Table 4: ARDL Bounds Test for Cointegration Results

T statistic	Value	K
Critical value bounds (Actual sample size = 23)	4.039890	3
Significance	I(0) Bound	I(1) Bound
10%	2.01	3.1
5%	2.45	3.63
2.5%	2.87	4.16
1%	3.42	4.84

Note: *, **, and *** represents 10%, 5%, and 1 % respectively level of significance, respectively. Source: Authors' drawing. Results obtained from Eviews 10

The ARDL bounds test confirmed a long-term correlation relationship between the investigated variables. The presence of cointegration is indicated by the calculated value (4.039890), which surpasses the I (1) bound critical values of 3.63 at the 5% significance level. This finding

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suggests stable and enduring relationships among the variables, allowing for meaningful inferences about the long-term associations between trade openness and environmental quality in South Africa.

Long-run elasticities, short-run elasticities, and ARDL error correction model. The error correction model and long- and short-run elasticities are presented in this section.

Long-run elasticities. This subsection presents the estimates of long-run elasticities amongst the variables with ARDL test procedures.

Table 5: Results of the long-run elasticities
Dependent variable: Environmental Quality

Variable	Coefficient	Standard-errors	t-statistics	p-values
LTO	0.219604	0.117327	1.871732*	0.0796
LPEC	0.163943	0.064507	2.541480**	0.0218
LPG	-0.026193	0.094993	-0.275740	0.7863

Note: *, **, and *** represents 10%, 5%, and 1 % respectively level of significance, respectively. Source: Authors' drawing. Results obtained from Eviews 10

Table 5.5 shows a positive relationship between trade openness and carbon emission at the 10% significance level. As a result, increasing trade openness by one unit raises carbon emissions by at least 0.21, all else being equal. This result makes sense in the case of South Africa, given that the country is one of the biggest producers of coal and other mineral products. The extraction of primary resources dominates the country's trade basket. Mineral mining is just one example of an activity that has a direct human impact on the local ecosystem and can have severe consequences (Soylu et al., 2021). One of the most pressing issues confronting modern-day South Africa is climate change, which has its roots in the unsustainable use of nonrenewable and leads to higher emissions and other forms of greenhouse gas pollution (Boateng, 2020). According to Soylu et al. (2021), carbon emissions are one of the Greenhouse Gases (GHGs) widely understood to be the primary factor in climate change and environmental degradation.

Ahmed et al. (2020) discovered a solid long-run symmetric association between trade openness, environmental degradation, and environmental sustainability. They concluded that, for the newly industrializing economies of India, China, Brazil, and South Africa, trade openness helps to lower CO2 emissions.

According to research by Antweiler et al. (2001), freer trade favors environmental quality when all four contaminants are considered together. However, different environmental indices lead to diverse empirical conclusions on the trade-environment nexus. According to biochemical oxygen requirement (BOD) per capita, water pollution is one indicator of the positive effects of trade liberalization. However, emissions of both nitrogen oxides (NOx) and carbon dioxide (CO2) are also attributable to them (Trans, 2020).

The findings show a positive relationship between primary energy consumption and carbon emissions in South Africa, and the result is statistically significant at 5%. Given that nothing else changes, these findings imply that a long-term rise of one unit in energy consumption increases 0.16 units in carbon output. According to Chontanawat (2019), one of the primary causes of climate change over the past ten years has been human activity, specifically the increased use of energy, which has increased CO2 emissions, environmental damage, and energy use. According to Tong et al. (2020), energy consumption is the primary driver of carbon dioxide emissions, which has triggered global warming issues.

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Carbon emissions decrease with increasing population, though not always significantly. It means that a 2% drop in emissions is achieved for every 1% rise in population, a result that is not statistically significant. This outcome goes against what would have been predicted. Because of their more developed economies and more significant populations, urban regions in China are viewed as major contributors to carbon emissions, according to research published (Zhao et al., 2022). In addition, seventy-five percent of the nation's energy use is associated with cities.

In conclusion, Table 5.5 demonstrates that, except for population growth, all projected long-run elasticities lead to statistically significant increases in carbon emissions.

Short-run elasticities and ECM. This subsection presents the estimates of short-run elasticities and an error correction model between the variables using an ARDL test procedure.

Table 6: Short-run elasticities

Dependent variable: Environmental Quality

Variable	Coefficient	Standard-errors	t-statistics	p-values
LCO2 PC (-1)	0.470132	0.206438	2.277355**	0.0368
LTO	0.167611	0.087125	1.923799*	0.0724
LPEC	0.457328	0.207996	2.198728**	0.0430
LPG	0.768863	0.362632	2.120227**	0.0500
CointEq (-1)	-0.763241	0.174233	-4.380580***	0.0005

Note: *, **, and *** represents 10%, 5%, and 1 % respectively level of significance, respectively. Source: Authors' drawing. Results obtained from Eviews 10

As shown in Table 5.6, carbon emissions spike by a noticeable 0.470132 units in the short run due to greater trade openness. The results align with Van Tran's findings (2020), which confirm the existence of an environmental problem; increased trade could have adverse effects on the planet. Proposed by the Kuznets system, the curve of economic activity.

According to the data, an increase of one unit in primary energy consumption in the short run is associated with a significant rise of 0.45 units in trade openness. As the world's population grows, so does the energy demand, leading to a rise in carbon dioxide emissions that has become a global issue, especially in developing countries undertaking industrialization to become industrialized (Sasana & Putri, 2018). The findings demonstrated that CO_2 emissions in Indonesia are positively impacted by the country's reliance on fossil fuels for energy production. Van Tran (2020) argues that the environment is deteriorating mainly due to three factors: increased energy use, finances, industrialization, and urbanization.

A population increase causes a 0.76-unit increase in carbon emissions right away. This result is in line with Sasana and Putri's (2018) findings, which showed that increasing population has a beneficial effect on CO_2 emissions in Indonesia. The Ohlan effects of greater population density, greater energy consumption, and more significant economic growth can be blamed for short-term increases in CO_2 emissions.

There needs to be more focus on how rising populations affect global CO_2 emissions, argues (Shi, 2001). Ohlan (2015) found that population density has a statistically significant beneficial effect on CO_2 emissions over the long term.

Evidence from recent years suggests that rising populations in both industrialized and developing countries are a vital contributor to global warming causing climate change (Bongaarts, 1992). According to Shi (2001), projected population growth alone will account for 50% of the rise in emissions from now until 2025.

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The results reveal a correct negative sign for the lagged error correction term at the 5% significant level, which was expected. These findings support the validity of the predicted long-term association. Furthermore, the results imply that about 76% (0.76) of disequilibrium adjusts to equilibrium a year after a system shock in South Africa (Toloui, 2018). Therefore, there is a stable long-term relationship.

In summary, all the variables were found to increase carbon emissions significantly. Lastly, the error correction significance level is very high, providing evidence of a stable long-term relationship.

Granger Causality Test. The Granger causality test was conducted once a long-run equilibrium cointegration was established, and the results are shown below.

Table 7: Results of the Granger causality test

	Obs	F-Statistic	Prob.
LTO does not Granger Cause LCO2PC	23	0.32548	0.7263
LCO2PC does not Granger Cause LTO		1.02306	0.3795
LPEC does not Granger Cause LCO2PC	23	0.05413	0.9475
LCO2PC does not Granger Cause LPEC		4.05965	0.0351**
LPG does not Granger Cause LCO2PC	23	3.96612	0.0374**
LCO2PC does not Granger Cause LPG		0.09730	0.9078
LPEC does not Granger Cause LTO	23	3.07358	0.0711*
LTO does not Granger Cause LPEC		4.52967	0.0255**
LPG does not Granger Cause LTO	23	2.42980	0.1164
LTO does not Granger Cause LPG		0.88598	0.4295
LPG does not Granger Cause LPEC	23	0.96377	0.4003
LPEC does not Granger Cause LPG		3.03514	0.0731*

Note: *, **, and *** represents 10%, 5%, and 1 % respectively level of significance, respectively. Source: Authors' drawing. Results obtained from Eviews 10

Table 5.7 shows that the hypothesis that trade openness does not cause carbon emission cannot be rejected since the p-value 0.72 is above the significant level. Again, the hypothesis that carbon emission does not Granger cause trade openness should not be rejected since the p-value 0.37 is beyond the 5% significance level. In both cases, we fail to reject the null hypothesis; hence the results indicate no causality nexus between trade openness and carbon emission. The empirical findings of Wang and Zhang (2020) and Le et al. (2016) also concur with this result. Omri (2013) also found that there is a unidirectional causal linkage between CO_2 emissions to energy consumption in the Middle East and North Africa (MENA)

At a p-value of 0.94, over the 5% threshold for significance, it is impossible to reject the null hypothesis that energy use does not cause carbon emissions. Meanwhile, using the Granger causality theory, it is essential to rule out the possibility that carbon emissions are unrelated to energy consumption. It is because the p-value of 0.03 is significantly lower than the 5% threshold. We cannot rule out the alternative hypothesis, which leads us to conclude that there is a unidirectional causation direction between energy consumption and carbon emissions, as well as between carbon emissions and energy consumption.

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The research was conducted by Vidyarthi (2013) to look at the long-term and causal link between energy consumption, economic growth, and carbon emissions in India. Long-term causality findings supported a direct link between CO_2 emissions and energy use. Albiman et al. (2015) researched Tanzania to determine what factors influence energy use, pollution levels, and GDP growth per person. The results showed a clear link between rising economies and energy use and subsequent pollution caused by carbon dioxide emissions.

The hypothesis will be rejected if the p-value is less than 0.03, meaning population growth does not cause carbon emissions. Additionally, as the p-value of 0.9 is greater than the 5% threshold for acceptance (H0: carbon emission does not Granger affect population growth), H0 should not be accepted. An association between these two factors that only goes one way is implied. It conforms with the findings of a unidirectional causation link reported (Shi, 2001).

Because the p-value is less than the significance level, we reject the null hypothesis that primary energy consumption does not affect trade openness. Similarly, assuming that primary energy use is unrelated to trade liberalization via the Granger causality mechanism is false. It is because the p-value of 0.03 is significantly lower than the 5% threshold. These findings corroborate those of Lu (2020), who looked at the links between real income, trade openness, and energy consumption to determine their impact on the environment's carbon footprint and found that openness to trade directly and positively influenced energy consumption. Evidence from this study demonstrates a strong correlation between economic indices and ecological footprint.

Since the p-value for the hypothesis that population growth does not influence trade openness is more than 0, the null hypothesis cannot be discarded. However, given that the p-value for the null hypothesis is 0.42, more than the 5% significance threshold, the hypothesis that trade openness does not Granger cause population should not be discarded. These findings disprove the existence of a causal relationship between economic growth and energy use. The findings are consistent with those (Ohlan, 2015).

The p-value of 0.40 is above the 5% significance level, rejecting the hypothesis that population growth does not affect energy use. The alternative theory, however, that population growth is not caused by energy use must be disproved. In this case, the p-value of 0.07 is far lower than the 10% threshold for significance. It demonstrates a unidirectional causal link between rising population and higher energy use. According to the findings of Aiyetan and Olomola (2017), there is a direct link between rising populations and factors, including carbon dioxide emissions, rising energy consumption, and expanding economies.

Diagnostic Tests. Results of Serial Correlation Table 8 shows the Breusch (1978) and Godfrey (1978) Lagrange Multiplier serial correlation LM test results.

Serial correlation test.

Table 8. Serial correlation results

Breusch-Godfrey Serial Correlation LM Test			
F Statistic	0.513517	Prob. F	0.6092
Obs R Squared	1.571951	Prob. Chi-Squared	0.4557

Source: Authors' drawing. Results obtained from Eviews 10

The calculated chi-squared value, 0.45, is statistically significant at a level higher than 5%. If there is no connection in the residuals, the null hypothesis must be accepted according to the decision criteria described in the prior chapter. Statistically, this suggests a noteworthy distinction between the two variables.

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A Heteroscedasticity Test's Findings Data from Engle's (1982) ARCH test for heteroscedasticity are shown in Table 9.

Table 9. ARCH test for heteroscedasticity results.

Heteroscedasticity Test: Breusch-Pagan-Godfrey			
F statistic	0.633426	Prob. F	0.7219
Obs*R Squared	5.247593	Prob. Chi-Squared	0.6298
Scaled explained SS	3.451898	Prob. Chi-Squared	0.8403

Above the 5% cut-off, chi-squared = 0.84 is statistically significant. Based on the decision-making process explained in the previous chapter, it was found that the null hypothesis of constant variance between the residuals could not be rejected. It was because they were homoscedastic. In other words, there are no indications of heteroscedasticity in the residuals.

Findings from the Normality of the Jarque and Bera (1980) and Jarque and Bera (1987) tests to determine the normality of residuals are shown in Table 5.10.

Normality test.

Table 10 Normality test.

Residuals normality test	
Jarque-Bera	2.8678
Prob	0.2383

Source: Authors' drawing. Results obtained from Eviews 10

The Jarque-Bera test assumes that the residuals are regularly distributed. The Jarque-Bera statistic's p-value (0.23) is over the 5% significance level at 5%. The Jarque-Bera results show that all series are typically distributed, and the study finds that the null hypothesis of the normal distribution cannot be ruled out at the 5% significance level.

Parameter stability. The parameter stability tests are illustrated below in Figures 3 and 4.

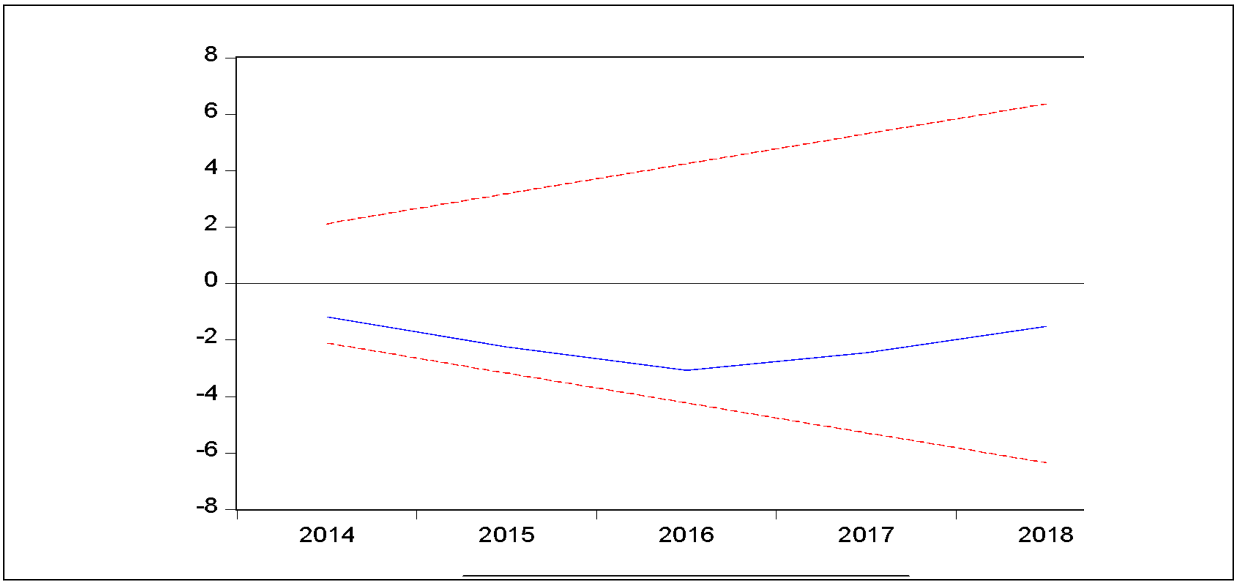

Figure 3: Results of the CUSUM test

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Figure 3 shows that the cumulative sum of recursive residuals openly indicates stability in the equation. In Figure 3, the blue line is within the area between the red dots confirming stability in the equation (Ahmed et al., 2020).

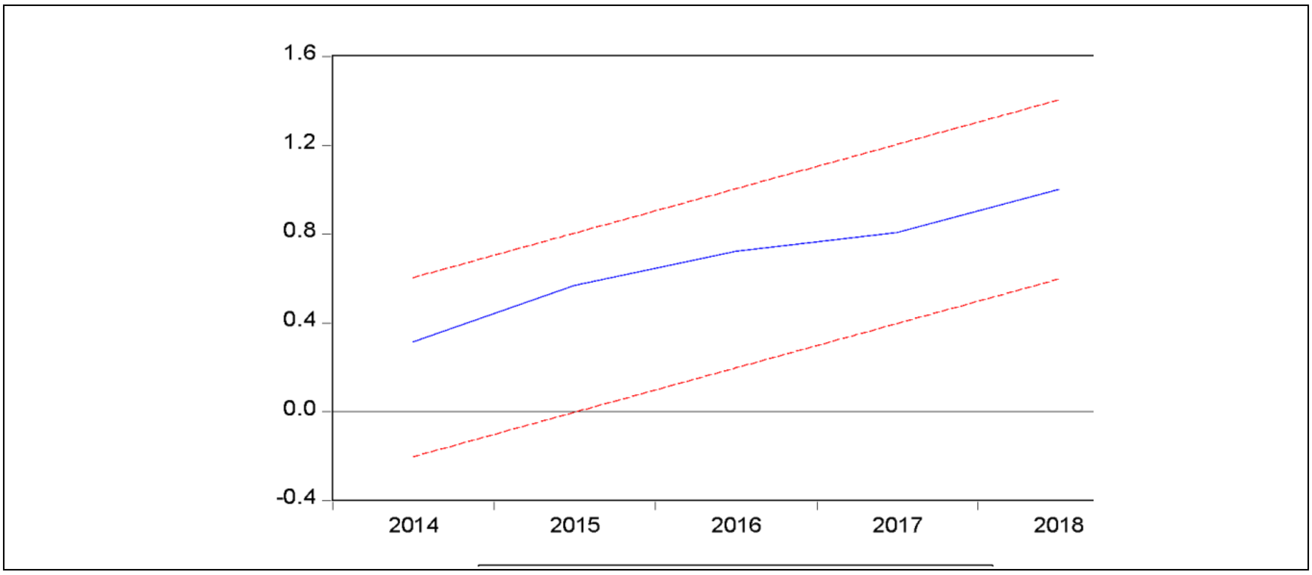

Figure 4: Results of CUSUM of Squares test

The cumulative sum of squares residuals (Figure 4) demonstrates that the equation is stable. Because the blue line in Figure 4 is contained within the region bounded by the red dots, we know the equation is stable (Ahmed, 2020).

In short, the results of CUSUM and CUSUMSQ reject the null hypothesis of unstable parameters, indicating that all model variables are steady. As a result, you can deduce that the relationship between trade liberalization and carbon emissions is both temporal and causal.

CONCLUSION

This study aimed to analyze the connection between trade openness and environmental quality in South Africa between 1994 and 2018, using econometric techniques. Literature reviews revealed that trade openness, primary energy use, and population expansion were significant factors in explaining environmental quality variations. The ARDL model was used to analyze the long-run and short-run elasticities, and the error correction model confirmed a strong and consistent long-term relationship between trade openness and environmental quality. The results indicated increased trade openness sometimes leads to a cleaner environment, as carbon emissions increased despite trade liberalization. Diagnostic tests for the model passed for serial correlation, normalcy, heteroscedasticity, and parameter stability.

The finding that trade openness increases carbon emissions in South Africa carries important implications across theory, practice, and policy. The result challenges traditional trade theories and suggests re-evaluating existing models to understand the complex relationship between trade and environmental outcomes. In the short run, increased trade activity may lead to higher carbon emissions as industries prioritize short-term profits. Policymakers must balance trade growth and carbon emissions reduction, imposing environmental regulations and pricing mechanisms to

discourage carbon-intensive practices. Green tariffs or carbon taxes on imported goods can incentivize adopting more sustainable practices.

Over the long run, comprehensive policies promoting sustainable production and renewable energy adoption are essential to counteract the negative impact of trade-induced carbon emissions. Trade agreements and policies must be revised to include environmental considerations, aligning economic growth with environmental protection. The rise in carbon emissions may also adversely affect public health due to air pollution, increasing healthcare costs. Regional and global cooperation is critical to addressing climate change collectively, as carbon emissions from trade can have transboundary effects. Collaborative efforts, including knowledge-sharing and technological transfers, can promote sustainable practices and combat the adverse effects of trade-induced carbon emissions on the environment and public well-being.

Recommendations. Future research should focus on understanding the underlying mechanisms that drive the positive impact of trade openness on carbon emissions in South Africa, as well as the factors contributing to the increase in emissions. Investigating specific industries' roles and production practices can provide valuable insights into how trade activities affect carbon intensity. Additionally, longitudinal studies tracking the long-term effects of trade openness on emissions and exploring the effectiveness of various policy interventions are necessary to inform evidence-based decision-making. Integrating multidisciplinary approaches, such as economics, environmental science, and policy analysis, will be essential to develop comprehensive strategies that promote sustainable trade and environmental conservation in South Africa.

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